Wax models of Europan tectonics. Michael Manga[1] and Antoine Sinton[2], [1]Department of Earth and Planetary Science, University of California, Berkeley, 94720, USA (manga@seismo.berkeley.edu) [2] Magistere des Science de la Matiere, Ecole Normale Superieure de Lyon, FRANCE (asinton@ens-lyon.fr).

Introduction: The Europan surface preserves a wide range of features that suggest extension [1], compression [2] and strike-slip motion [3]. Understanding the origin and dynamics that result in these surface features may ultimately provide insight into the rheological and thermal structure of the Europan ice shell, and its evolution through time.

Developing theoretical and numerical models for Europan tectonics is challenging because they should involve coupled brittle failure and (nonlinear) viscous flow. The mathematical complexity of the problem but geometric simplicity of phenomena on the Earth that involve plates (e.g., plate tectonics, solid crusts on lava lakes) has motivated several studies of transform and microplate dynamics using wax analoguess [4-5]. We thus built an experimental apparatus to simulate Europan ice tectonics, and performed a set of experiments with model parameters appropriate for Europa.

Experimental approach: Our experimental approach follows that of previous studies [4-5] but also allows for periodic surface deformations that arise, for example, from tidal deformation. In these experiments, solid wax simulates the brittle, elastic layer and the molten wax simulates the region that deforms as a viscous fluid, either warm ice [6] or liquid water [7]. The solid layer of wax actually consists of two sublayers – a brittle layer that can break and a ductile layer that deforms viscously.

Figure 1 shows the experimental apparatus. The wax container (right) is heated by a resistance heater until the wax is entirely molten. The surface of the wax is then cooled with the fan shown in the upper right. A layer of solid wax develops at the surface, and the steady-state thickness of the solid wax layer is controlled by adjusting the heat flux provided by the resistance heater. Once the solid wax layer has thickened to its steady-state value, the motor (left) is turned on. The various signal generators, amplifiers, and power supplies shown on the left control the horizontal motion of the vertical plate that is immersed in the wax tank. We can control the rate of secular extension (or compression), and the period and amplitude of any time-dependent or oscillatory deformation.

Scaling: The use of waxes as analogues for geological materials has perhaps been most successful in studies of lava flow morphology and emplacement [see review in 8]. Wax models of lava flows exhibit the full range of morphologies, from pillows, to rifted flows, to folded flow and finally sheet flows with increasing extrusion rate.

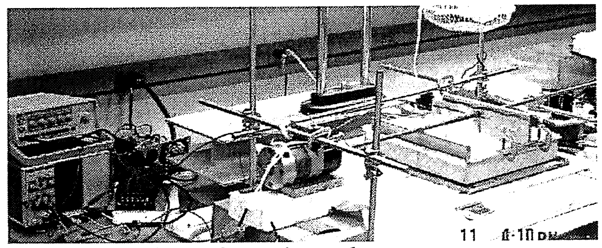

Figure 1: Photo of experimental apparatus.

The dimensionless parameter that governs lava flow morphology (at least in the lab experiments), and allows the analogue experiments to be scaled to real lava flows, was found to be ψ = cooling time scale / deformation time scale.

A second parameter is needed to characterizes the relative magnitudes of secular dilation and tidal cycling. This is denoted γ and is defined in [7].

For a brittle ice layer thickness of 1 km and using a tidal strain rate to estimate the deformation time scale, we obtain $\psi \sim 54$ for Europa. Given the uncertainties of the various parameters that affect ψ, we consider $10 < \psi < 300$ and $0 < \gamma <$ infinity in our experiments.

Results and conclusions: Our wax experiments can produce a wide range of surface features that, at least qualitatively, resemble many of the surface features on Europa including bands and ridges. We do not, however, create and preserve features that clearly resemble chaos and double ridges. Interestingly many of the patterns more closely resemble images of Ganymede's surface [9]

A typical experiments is shown in Figure 2. The overall width of this band is about twice the total amount of extension. The individual ridges that make up this band are folds (half a wavelength long) that form during the compression phase of the periodic deformation. Each fold and ridge are bounded by what was once a fault in the brittle wax layer. The complex pattern of these ridges arises when, due to shear localization, rifting jumps from one location to another.

We were able to perform a total of 26 experiments (before the first author accidentally allowed the apparatus to self-destruct) for different values of ψ, γ and thickness of the solid wax layer. Our preliminary conclusions are

- Band-like features can form if $\gamma > 0$. Small scale folds (Figure 3) within the bands are not always parallel to each other as a result of shear localization [10]. Bands may have complex morphologies, as illusratedd in Figure 2 and 4.

- The width of band-like features can in some cases be quite a bit greater than the total amount of extension (see Figure 4 where there is no net extension).
- Features resembling class 2 structures [7] form for γ < about 0.2 and ψ less than about 100.
- Features that most closely resemble double ridges form only where strike-slip motion dominates and where γ is small.
- The wavelength of small scale structures (folds) is similar to the total thickness of the solid wax layer.Figure 2: Band-like feature (γ = 0.1, ψ = 30)

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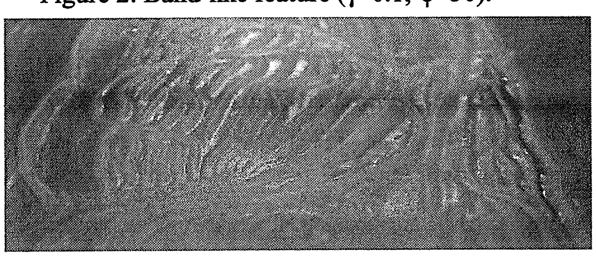

Figure 3. Band containing nonparallel ridges that form from strain localization (γ = 0.4 and ψ = 20)

Finally, we also performed some experiments in which the thickness of the brittle layer was variable. Figure 4 shows an example of the structures that develop. Where the brittle layer is thinnest (middle of photo, box 2, where ψ = 0.01) structures extend radially from the region where the brittle layer is thinnest. On the sides of the photo, ψ = 30 and the band structure is similar to that in Figure 2.

If the processes that occur in the lab experiments are indeed similar to those that produce bands, the morphology of bands and features within bands can be used to infer the thickness of the brittle layer, and identify regions where the brittle layer is thinnest.

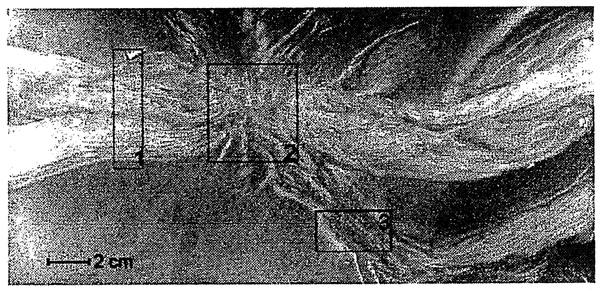

Figure 4: Solid layer has a variable thickness (ψ~ 0.01 in box 2 and 30 near the sides of the photo; γ = 0).

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